X. "Report of the Examination of some of the Scientific Instruments employed by the late Dr. Joule." By J. D. CHORLTON, B.Sc., Joule Scholar. Communicated by Professor ARTHUR SCHUSTER, F.R.S. Received March 17, 1896.

Having been appointed by the Royal Society to the Joule Scholarship, and entrusted with the examination of some of the instruments employed by Joule in his scientific work, I called upon his son, Mr. B. A. Joule, in whose possession were such of the instruments as had not already been presented to the South Kensington Museum or other places. Mr. Joule very kindly placed the instruments at my disposal, and I am much indebted to him for the trouble he took in searching his house for anything that might have been laid by.

Most of the instruments I removed to the Physical Laboratory at Owens College, where there were greater facilities for examining them. Throughout the research I have been greatly aided by the two volumes issued by the Physical Society of London, in which all Joule's scientific papers are collected, and in every case I have referred to the pages in these volumes where a complete description of the instrument under examination may be found, with accompanying diagrams.

The following list comprises all the more important instruments remaining at Sale:—

Two electric current meters.
The last apparatus for determining the mechanical equivalent of heat.
An electromagnetic engine.
A new balance.
A mercurial air exhauster.
A new form of dip circle.
Two air pumps.
Several thermometers and an instrument for calibrating thermometers.
Two tangent galvanometers.

All of these instruments were either made by Joule himself or from his design and under his directions.

Two Electric Current Meters ('Collected Papers,' vol. 1. pp. 584—589, also p. 542).

As a good deal of discussion has lately been carried on about the difference in the value of J obtained by different methods, it seemed important to find the value in our present units of the constant of the

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current meter which Joule used in his determination of the equivalent of heat by the electrical method, and it would be interesting either to confirm the value which Joule gives, or to apply some correction to it in case the constant were found to be rather different from that assumed by him.

I found two current meters at Sale, one of them being the meter used in the determination of the equivalent of heat from the thermal effects of electric currents. This meter is contained in an oblong wooden box, 4 ft. in length and about 18 in. in height and width, the balance beam is made of wood, and is suspended from the sides of the box by stretched wires which, after passing along each side of the beam, suspend a flat horizontal coil of wire 1 ft. in diameter; above and below this coil are placed two fixed coils exactly similar to the suspended one. The current is passed through the coils in such a way that the top coil attracts while the lower repels the movable one, electric communication with which is ingeniously made by means of the suspending wires.

At the other end of the beam is a counterpoise which brings the movable coil into a position about midway between the two fixed coils when no current is passing. When an electric current is passed the suspended coil is attracted upwards and is brought back into its former position by means of weights placed on a shelf attached to it.

Joule says of this balance: "The strength of a current can in this manner be determined in absolute measure; for the area of each of the three coils being called a, the weight required to counterpoise the force with which the suspended one is urged w, the force of gravity g, and the length of wire in each of the coils l, the current

$$c = 1/2l \sqrt{\frac{agw}{2\pi}} \,(1 + \text{correction}),$$

the correction being principally due to the distance between the fixed coils. In my instrument, in which this distance is 1 in., the diameter of the coils being 12 in. and their interior core 4 in., this correction was proved by experiment to be 0·1185" ('Collected Papers,' vol. 1, p. 543).

Owing, however, to the difficulty in obtaining an exact measure of the distance between the fixed coils, Joule abandoned this result and found the constant of the instrument by comparing it with a tangent galvanometer.

In order to re-determine this constant, I passed a current through this balance and through one of Lord Kelvin's current balances in the Physical Laboratory at Owens College placed in series with it.

Thus, if w be the weight necessary to bring back the movable coil

into the position it occupied before the passage of the current—that is, into a position midway between the two fixed coils—and c be the current as measured by the "Kelvin Balance," then, since the attracting force between two coils depends on the square of the current,

$$c = K\sqrt{w} \quad \text{or} \quad K = c/\sqrt{w},$$

where K is the constant of the instrument.

The following observations were made :—

Current c.	Weight w.	$\sqrt{w}$.	Constant.
4·469	20·92 grams	4·574	0·9770 ampère
3·938	16·25 „	4·030	0·9769 „
3·455	12·52 „	3·338	0·9767 „
3·108	10·13 „	3·183	0·9764 „
2·604	7·11 „	2·6665	0·9765 „

It will be noticed that the value of the constant slightly, but fairly regularly, decreases as the current decreases.

I noticed this decrease in all the experiments I made with both this balance and the newer one, but was unable to find any explanation.

I do not think it could be due to leakage through the wood of Joule's balances, for I tested them thoroughly for leakage and could find none, nor could the electrostatic force between the coils be the cause, for this, on calculation, appears to be quite inappreciable.

For reading the balance a needle is provided fixed horizontally into the end of the balance beam, the end of this needle oscillates in front of a graduated scale attached to one of the sides of the box, the observer's eye being placed to a small hole cut in the opposite side of the box and thus any errors of parallax avoided.

By this means the weight on the movable coil could be easily adjusted to less than 5 milligrams, and as the weight varies with the square of the current, the half only of any error made in the determination of the weight appears in the estimation of the current.

On reference to the above table it appears that with this balance 10 grams means about 3 ampères, so that 3 ampères may be measured correctly to 1 part in 4,000; it is also evident that as the weight varies with the square of the current the balance is much more accurate for large than for small currents.

A source of some trouble is a constant changing of the zero, that is to say, the counterpoise at the end of the beam has to be frequently adjusted in order to bring the movable coil into its zero position halfway between the two fixed coils. I may mention that there is no accurate method of bringing the suspended coil exactly into this mean position, but by experiment I found that the exact point fixed upon as zero is immaterial, the value obtained for the constant being the same, whatever point, within certain limits, be chosen as zero.

The second electric current meter was constructed some years later, and while its design is almost exactly similar to the one just described, its construction is in every way more finished and elaborate, and as it is considerably smaller than the old balance (exactly $\frac{3}{4}$ths the size), it is more convenient to work with.

A very complete description of this balance is given in the 'Collected Papers,' vol. 1, pp. 584—589, it is, therefore, unnecessary to describe it at length here, I will only mention that a great improvement is made by the use of copper tape instead of copper wire in the coils, the flat tape does not take up nearly as much space as the wire, so that two coils made of tape will contain many more revolutions and consequently will attract each other more strongly than two coils of the same diameter made of wire.

This may be seen from the following determination of the constant by means of the Kelvin balance.

Current c.	Weight w.	$\sqrt{w}$.	Constant.
4·468 ampères	49·98 grams	7·067	0·6322 ampère
3·880 ,,	37·72 ,,	6·140	0·6319 ,,
3·468 ,,	30·13 ,,	5·489	0·6318 ,,
3·159 ,,	25·02 ,,	5·002	0·6315 ,,
2·638 ,,	17·47 ,,	4·178	0·6314 ,,
2·284 ,,	13·10 ,,	3·019	0·6313 ,,
2·019 ,,	10·24 ,,	3·198	0·6313 ,,

Here again the steady decrease of constant with decrease of current is noticeable.

From the above table it will be seen that when 3 ampères are passing, the weight needed to restore equilibrium is about 25 grams, while it will be remembered that in the former balance only 10 grams were needed, and as in this case also the weights could be adjusted to 5 milligrams or less, 3 ampères may be measured with this balance correctly to 1 part in 10,000.

Joule's determination of the value of J by the electrical method was undertaken at the request of the Committee on Electric Standards appointed by the British Association; the result he obtained was published in the *B.A. Report*, Dundee, 1887.

He experienced a great deal of trouble in measuring the current because of the difficulty he found in determining the exact value of the earth's horizontal magnetic force at the time and place of the experiment.

The arrangement he finally adopted was to pass the current through a tangent galvanomter and then through an electric current meter placed in series with it, the current being measured by the galvanometer and the current meter being used to determine the earth's horizontal magnetic intensity; this was effected as follows :—

"Many careful observations of the horizontal intensity by an improved method on Gauss and Weber's system were made alternately with observations of the deflections of a tangent galvanometer and the weighings of the current meter when the same currents traversed each in succession. Then calling the horizontal intensity H, the angle of deflection θ, and the weighing w, there was obtained a constant

$$k = \frac{\mathrm{H} \tan \theta}{\sqrt{w}} = 0{\cdot}17676.$$

"Hence with these instruments

$$\mathrm{H} = \frac{0{\cdot}17676\sqrt{w}}{\tan \theta}.$$

"The experiments for the determination of the horizontal intensity could be effected in a few minutes." ('Collected Papers,' vol. 1, p. 545.)

Of course, as soon as H is known the current is easily measured by the tangent galvanometer, for we have the usual expression

$$\text{Current} = \frac{\mathrm{H}r}{2\pi} \tan \theta,$$

where r is the radius of the galvanometer coil and θ the deflection of the needle.

Now, since Joule found the constant

$$\mathrm{H} \tan \theta = 0{\cdot}17676\sqrt{w},$$

while the galvanometer coil, when measured in several places with a standard foot rule, had a mean radius

$$r = 0{\cdot}62723 \text{ ft.},$$

$$\text{the current } c = \frac{0{\cdot}62723 \times 0{\cdot}17676\sqrt{w}}{2 \times 3{\cdot}1416},$$

or
$$c = 0{\cdot}017645\ \sqrt{w}.$$

The units are grains and feet; on conversion to grams and centimeters $c = 0{\cdot}9742\ \sqrt{w}$ ampères, that is to say, the constant of the balance is 0·9742.

In the case of the newer balance, Joule found the constant by the same method to be 0·6346.

On referring back to the examination of the current balance, it will be seen that for a current of about 3 ampères or 3·5 ampères, this being the current at which Joule generally worked in these experi-

ments, the constant of the old balance as determined by means of the "Kelvin balance" is 0·9766, while that of the new balance is 0·6316. So that in the case of the old balance I find a constant which is greater than that given by Joule by 2·5 parts in a thousand, while the constant of the new balance seems to come out about 4·6 parts in a thousand less than the value given by Joule.

My determination of the constant of the new balance is, however, not to be relied upon, because I found it exceedingly difficult to replace the upper fixed coil, which had become unwound and had to be removed in order to be rewound in exactly the same position as it formerly occupied, so that the distance between the two fixed coils may have been altered, and in making an experiment to determine the amount of error which a slight increase in the distance between the two fixed coils would be likely to produce in the constant, I found that on increasing the distance, which is about 1 in., by 1/16 of an inch, an increase of about 1 per cent. appeared in the constant.

Fortunately, although the upper coil of the old balance had also become loose, there was no difficulty in replacing it exactly in its former position.

The "Kelvin" balance had been tested by silver electrolysis some months previously, and found to be correct, and in order to assure myself that it had not changed in the meantime, I afterwards again tested it, with the same result. As no trace of leakage could be detected in the "Joule" meter, it would therefore seem that some error must have been made in the measurement of the radius of the galvanometer or in the determination of H. Unfortunately, on examining the tangent galvanometer, I found that the coil used in these experiments, which consisted of a single circle of 1/10 in. copper wire, had got displaced, and could not be replaced exactly in its former position; in fact the measurement of the diameter would have been liable to an error of 1 per cent.

I have not, then, been able definitely to discover an error in any of Joule's measurements, and can only indicate the probability that on account of error either in the measurement of the radius of the galvanometer or in the determination of the earth's horizontal magnetic force, the currents in these experiments were estimated about 2·5 parts in a thousand less than their real value, and that as the heat developed depends on the square of the current, the value of J given by these experiments may be too small by five parts in a thousand.

The experiments are divided into three series. The value obtained from the first series was 786·3, from the second 787, from the third 782·4; but Joule says that the extra precaution taken in the last series entitles the last figure to be taken as the result of the inquiry.

The value then obtained for J from these experiments was 782·4

foot-pounds at Greenwich at a temperature of 18·6°, but this assumes the B.A. ohm (104·8 centimeters of mercury) to be correct. If we take the present unit (106·3 centimeters of mercury), this reduces to 771·4, which agrees very fairly with Joule's last value, 772·55 at 16·5°, obtained from the friction of water. If, however, Joule's current meter measured wrongly, as now seems probable, by about 2·5 parts in a thousand, it would seem that the equivalent of heat derived by Joule from the electrical method must be taken as 775·3, and Joule's results therefore seem to agree with those of more recent experimenters in pointing to a systematic discrepancy between the value obtained for J by mechanical methods on the one hand and electrical methods on the other. The thermometer used in the experiments has been examined by Professor Schuster, and his result ('Phil. Mag.,' June, 1895) is that if T_j represent the reading on the Joule thermometer, and T_N the reading on the nitrogen thermometer of the Bureau International, then $T_j = T_N (1 + 0{\cdot}0024)$. Joule's value for the equivalent then from the electrical method is 777·2 foot-pounds at Greenwich on the scale of the "Paris" nitrogen thermometer at a temperature of 18·6°. Professor Schuster and Mr. Gannon, at the close of their paper on "The Determination of the Specific Heat of Water in Terms of the International Electric Units" ('Phil. Trans.,' vol. 186, 1895, A, pp. 415—467), compare the values obtained for J by different experimenters, and give a table of equivalents in foot-pounds at Greenwich at 19·1°, referred to the "Paris" nitrogen thermometer.

Joule.	Rowland.	Griffiths.	Schuster and Gannon.
774	776·1	779·1	778·5

Introducing the value obtained by Micelescu, which is given by Schuster and Gannon as 776·6 at 15°, and which, if we take as the temperature correction the mean of the values given by Rowland and Mr. E. H. Griffiths ('Phil. Trans.,' vol. 184, 1893, A, p. 361), reduces to 775·1 at 19·1°, the table becomes:—

Mechanical method.			Electrical method.		
Joule.	Rowland.	Miculescu.	Griffiths.	Schuster & Gannon.	Joule.
774	776·1	775·1	779·1	778·5	777·1

The first three numbers were obtained by mechanical methods, the last three by electrical methods.

Professor Schuster and Mr. Gannon remark that Rowland's number referred to the Paris nitrogen thermometer would probably be smaller by one unit; this being the case, the higher values given by the electrical as compared with the mechanical methods are very noticeable.

Joule's value subject to the above correction assumes the electro-chemical equivalent of silver to be 0·001118; if the correction be neglected, his value is obtained from purely electro-magnetic measurements, and is 773·3, closely agreeing with his value obtained from frictional experiments. The values of Griffiths and Schuster and Gannon also depend on silver electrolysis.

The last Apparatus for Determining the Mechanical Equivalent of Heat ('Philosophical Transactions,' 1878. Part II; also 'Collected Papers,' vol. 1, pp. 632—657).

Joule gives the following account of the circumstances which induced him to undertake the construction of this apparatus :—

"The Committee of the British Association on Standards of Electrical Resistances, having judged it desirable that a fresh determination of the mechanical equivalent of heat should be made, by observing the thermal effects due to the transmission of electrical currents through resistances measured by the unit they had issued, I undertook experiments with that view, resulting in a larger figure, 782·5, than that which I had obtained from the friction of fluids, 772·6. The only way to account for the discrepancy was to admit the existence of error either in my thermal experiments or in the unit of resistance. A Committee consisting of Sir Wm. Thomson, Professor P. G. Tait, Professor Clark Maxwell, Professor B. Stewart, and myself were appointed at the meeting of the British Association in 1870, and with the funds thus placed at my disposal I was charged with the present investigation for the purpose of giving greater accuracy to the results of the direct method." ('Collected Papers,' vol. 1, p. 632).

The method adopted was to revolve a paddle in a suspended vessel of water, and to find the heat produced, the work being measured by the force required to hold the vessel from turning, and the distance run as referred to the point at which the force was applied.

The result of the paper was to confirm the earlier experiments, and to show that the B.A. ohm was in all probability wrong to the extent of 1·3 per cent., the final value of the equivalent by this method being 772·55.

The apparatus is intact in all essential points, and it is, I believe, the intention of Mr. Joule to send it shortly to the South Kensington Museum.

An Electro-magnetic Engine ('Collected Papers,' vol. 1, pp. 1—3).

This little instrument is of interest because it was the occasion of the first paper Joule ever published which appeared in 'Sturgeon's

Annals of Electricity,' vol. 11, p. 122, being reprinted to form the first of the collected papers. The paper is dated January 8, 1838, so that this machine must be one of the first electric motors intended for practical use.

I did not attempt to test the efficiency of the motor because the wire passing round the magnet was broken in several places, and to have pieced it together would have involved the unwinding and re-winding of the whole of the wire on the motor.

A New Balance ('Collected Papers,' vol. 1, pp. 552—561).

A description of this instrument was read before the Manchester Literary and Philosophical Society on March 20, 1886, and may be found in the 'Proceedings of the Society' (vol. 5, pp. 145—165).

The balance beam is suspended by a steel wire fastened to the sides of the containing box, a leaden weight is let into one end of the beam, from the other end is slung a stage for the object to be weighed, and for the weights; the centre of the box lid is cut out and roofed by means of a rectangular glass box; from the centre of the upper edge of the beam there projects vertically a light wooden rod which carries a small glass vessel for containing lead shot, by the addition of which the stability of the beam may be decreased to any required extent; to the extremity of this rod a needle is fastened which serves as an index, and oscillates in front of a graduated paper scale fixed on one of the sides of the glass box referred to above. I found the balance intact, with the exception that the steel wire supporting the beam was broken; this, however, was easily replaced.

The feature of the balance is its exceeding simple and inexpensive construction; made as it is almost entirely of wood, it could be easily constructed by anyone possessing a little skill in the use of tools for a very trifling cost.

The sensibility of the balance of course depends entirely upon the amount of lead in the small glass bottle referred to.

The following numbers were obtained when the sensibility had been increased as far as was possible consistently with stability.

	Position of rest of pointer.			
Weight on stage.	1st expt.	2nd expt.	3rd expt.	Mean difference.
213·140 grams	1·1	1·1	1·3	
				1·3
213·150 „	2·4	2·3	2·5	
				1·2
213·160 „	3·6	3·3	3·7	
				0·55
213·165 „	4·1	4·1	4·25	

So that the average difference for 1 centigram increase of weight is 1·2 scale divisions, and as each division can be read to tenths, an article can be weighed by the balance to 1 milligram.

Joule says that he could weigh with this balance to the hundredth part of a grain, that is to the fifteen hundredth part of a gram.

To test this I made a number of determinations of the weight of a glass cube which had been previously weighed by an Oertling balance and ascertained to be 207·020 grams in weight.

The mean of these determinations gave a value of 207·0197 grams, agreeing with the value obtained by the Oertling balance to less than half a milligram. Some of the values, however, differed from the mean by as much as 2 milligrams. Still, this is a remarkable result for a balance made entirely of wood.

Mercurial Air-exhauster ('Collected Papers,' vol. 1, pp. 623—627.)

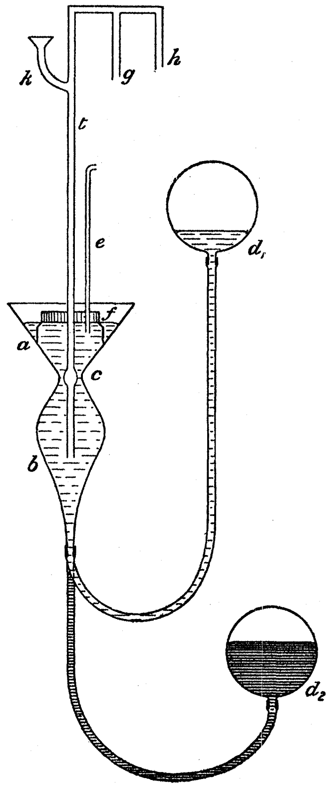
An account of this air-pump was read before the Manchester Literary and Philosophical Society (vol. 12, p. 57; vol. 13, p. 58; vol. 14, p. 12).

The pump has been altered and improved several times, as may be seen from Joule's papers; the form in which I found it at Sale is, I think, the final form it took after all improvements had been made.

It consists of a large, thistle-shaped, glass vessel, *a* and *b*, one end of which is connected by an india-rubber tubing to a glass globe containing mercury; the entrance tube, *t*, is blown out at *c*, and the bulb so formed is ground into the neck of the thistle glass, so as to make a joint which is impervious to mercury. To collect the pumped gases, Joule finally used an inverted glass vessel, *f*, fitted with an india-rubber cork, through which passes the entrance tube, *t*, and the exit tube, *e*. The entrance tube should be connected at *h* to the vessel to be exhausted, and at *g* to a mercury manometer, which I was unable to find. The glass work is supported by a wooden post, 7 ft. high, which Joule, when working with the pump, clamped to the edge of a table.

The method of working the pump is first to raise the globe, *d*, to the upper position, d_1, whereupon the mercury runs down, fills the vessel, *b*, lifts the bulb at *c*, and fills the upper part of the thistle-glass, driving the air out by the exit tube *e*; *d* is then lowered to the position d_2, whereupon the mercury runs out of *b* back into *d*, and *b* again fills with air from the entrance tube; this operation is repeated until the pressure in the manometer reaches the lowest limit obtainable with the pump. The funnel, *k*, is used to introduce sulphuric acid for removing aqueous vapour.

Joule gives the following list of lowest pressures obtainable with sulphuric acid of various strengths:—



Sulphuric acid.	Water.	Pressure in inches of mercury.
3	0	Inappreciable.
3	1	"
3	2	0·01 inch at 70
1	1	0·03 " 63
1	2	0·15 " 63
1	4	0·30 " 55
0	1	0·37 " 47

On examination the india-rubber tubing proved to be quite rotten, and had to be replaced, and also as was stated before, the manometer was missing.

I did not make any experiment to test the pump, because results at all comparable with those obtained by modern instruments could not be expected from a pump whose joints are made of india-rubber tubing.

A new Dip-circle ('Collected Papers,' vol. 1, pp. 575—584).

The instrument was described at a meeting of the Manchester Literary and Philosophical Society (vol. 8, p. 171).

Joule was not satisfied with the usual method of supporting the needle of a dip-circle in which the cylindrical axle of the needle is made to roll on agate planes, and, after trying several methods of suspension, finally adopted one in which the axle of the needle rolls on silk fibres. His dip-circle received successive improvements, until it finally assumed the form described in the 'Collected Papers,' on p. 577. A drawing of the instrument was exhibited at South Kensington, in the Loan Collection of Scientific Apparatus, 1876, and afterwards remained there.

Joule says that he could make an observation of the dip with this instrument in about ten minutes, and that the difference between any two consecutive determinations hardly ever exceeded a fraction of a minute. I must confess, however, that I could not work with the instrument to anything approaching that degree of speed and accuracy. In the first place, the usual method of placing the needle in the plane of the magnetic meridian, *i.e.*, by finding the position in which the dip is 90°, and then turning the instrument 90° in azimuth, is impossible with this instrument, as may be seen from a glance at its form. The only method, then, of finding the magnetic meridian is to take successive observations with the needle in different planes until one is found in which the dip is a minimum; this is a rather lengthy operation, and may necessitate five or six readings before the actual observations of the dip can be commenced. The chief difficulty, however, in working with the instrument was the great friction between the axle of the needle and the silk fibres; the original fibres attached by Joule were broken, and I had to attach new ones. In what way the new fibres differed from the old ones I do not know, but in my observations the friction, and consequently the difference, between the readings was so great, and the tendency of the fibre to slip to different parts of the axle, and so to throw the needle out of the vertical plane, together with the vibrations incident upon the method of suspending the vertical circle, so troublesome, as, for all practical purposes, to render the instrument of little use. Joule seems to have sometimes used spider-threads instead of silk fibres, but the only needle I could find belonging to the dip-circle was too heavy for spider-threads.

Two Air-pumps ('Collected Papers,' vol. 1, pp. 171—189, also p. 531).

Of these two pumps the older was used in the research: "On the Changes of Temperature produced by Rarefaction and Condensation of Air."

The paper was published in the 'Philosophical Magazine,' May, 1845, and also in the 'Collected Papers,' pp. 171—189, where a full description may be found, including a detailed account of a new stop-cock.

A notice of the second pump, a compressing air-pump, may be found on p. 531 of the 'Collected Papers;' in this instrument the cylinders, two in number, were made of great length, in order to get rid of the necessity of packing, being 20 in. long and 2 in. in diameter. Joule says that air can be readily compressed by the pump to 16 atmos. These two pumps were made under Joule's direction, and with a little care would be in perfect working condition.

The Thermometers.

The thermometers used in Joule's determinations of the mechanical equivalent of heat have already been examined by Dr. Schuster, 'Phil. Mag.,' June, 1895. Several thermometers, however, of less importance remain at Sale.

Instrument for Calibrating Thermometers.

This is a small instrument, made for Joule by Mr. Dancer. It consists of a brass base with a groove for holding thermometers, over this is fixed a small microscope, which may be moved forwards by means of a fine screw with a graduated head; the instrument is mentioned on p. 175 of the 'Collected Papers,' vol. 1.

Two Tangent Galvanometers.

These galvanometers were not constructed by Joule himself, but were made for him, and under his directions, by the firm Abraham and Dancer, of Manchester; one of these instruments was used for measuring the electric current in the determination of the mechanical equivalent of heat from the thermal effects of electrical current; its needle is suspended by a silk fibre, the torsion of which, in accurate experiments, must be allowed for. I found three coils belonging to the instrument; one of them consists of a single circle of thick copper wire, the second contains about ten revolutions of finer wire, and the third a large number of revolutions of still finer wire. These coils are mounted on wooden rings 12 in. in diameter, which slip on to the framework of the galvanometer, and may be removed or changed in a few seconds.

The smaller instrument, which is about half the size of the larger, has three similar coils, 6 in. in diameter, belonging to it.

I hoped to have been able to discover some of the MSS. of Joule's

papers, but Mr. Joule told me that he had never come across any in the house, and did not think that any had been brought to Sale.

The only book I could find containing notes by Joule was a small book partly filled with memoranda relative to the brewery, at one end is a draft of the paper "On the Determination of the Equivalent of Heat from the Thermal Effect of Electric Currents," at the other end are numerous readings of the barometer, taken day by day, and extending over a period of several months.

The following extracts are taken from the catalogue of the Collection of Scientific Apparatus at South Kensington.

Apparatus used by Dr. Joule, F.R.S, for ascertaining the Mechanical Equivalent of Heat.

218. *Revolving Electro-magnet*, used in 1843 for ascertaining the *Mechanical Equivalent of Heat.*

Part of the apparatus used in 1843 for the determination of the mechanical equivalent of heat: viz., a revolving piece, holding a glass tube filled with water, and containing an electro-magnet. This worked between the poles of a powerful magnet; and the heat evolved by the rotating electro-magnet was measured by the rise of temperature of the water. In this manner the quantity of heat lost by the circuit was ascertained when the machine worked as an engine; and, on the other hand, the quantity of heat produced when work was done on the machine was also measured. 833 ft.-lbs. was the mechanical equivalent of a degree F. in 1 lb. of water, as determined by these first experiments.

219. *Calorimeter*, containing a *revolving agitator*. This was employed in the experiments on the heat evolved by the friction of water, made in 1849. The equivalent arrived at was 772 ft.-lbs.
220. *Cast-iron Vessel*, containing *Friction Disk*, to revolve under mercury. Used in 1849 to determine the mechanical equivalent of heat by the friction of cast iron against cast iron. The equivalent arrived at was 775 ft.-lbs.
221. *Electro-magnet* consisting of a broad plate of $\frac{1}{2}$-inch iron having a bundle of copper wires coiled round it. Employed in the first determination of the mechanical equivalent of heat.
222. *Apparatus* for determining the temperature of water at its maximum density.

Used in the experiments on atomic volume and specific gravity by Playfair and Joule ('Memoirs of the Chemical Society,' vol. 3, 1846). It consists of two tall vessels, connected together by a stop-cock at the bottom, and a trough at the top. A minute difference of the

temperature of the water in one of the vessels from that of the maximum density, determines a flow through the trough to the vessel still nearer the temperature of maximum density. The temperature of water at maximum density was thus shown to be 39·1.

223. *Paddle Apparatus*, by means of which Dr. Joule determined the dynamical equivalent of heat. Described in 'Philosophical Transactions' for 1850, p. 65. (Sir William Thomson.)

592. *Drawing of Mercurial Air Pump* (1872). (J. P. Joule, D.C.L., F.R.S.)

By alternately lifting and lowering the bulb attached to the flexible tube, the air being dried by the admission of sulphuric acid through a glass valve at the upper part of the perpendicular tube, a very excellent vacuum may be obtained in a short time.

1118. *Surface Electro-Magnet* made in 1840. When fully excited, the armature is retained with a force of upwards of a ton. (J. P. Joule, D.C.L., F.R.S.)

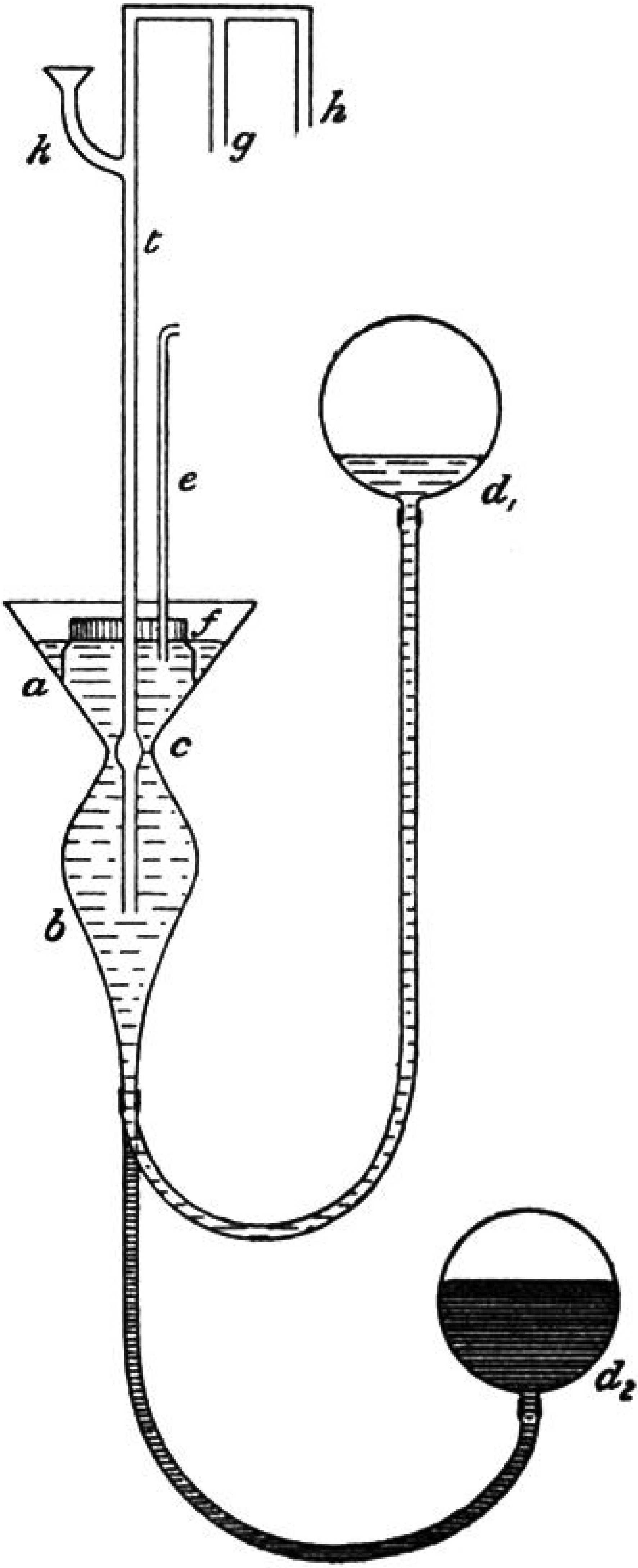
1144. *Electro-Magnet for Induction and Diamagnetic Experiments*, made in 1850, of a broad plate of annealed iron, so as to obtain a large induced power from a small voltaic source. (J. P. Joule, D.C.L., F.R.S.)

The coil is composed of a bundle of copper wires, and has a resistance about equal to that of a Daniell's cell, exposing a surface of 1 ft. square.

1190. *Drawing of a Dip Circle.* (J. P. Joule, F.R.S.)

The needle, constructed of a thin ribbon of annealed steel, weighing 20 grains, is furnished with an axis made of a wire of standard gold. This axis is supported by threads of the Diadema Spider attached to the arms of a balance suspended by a fine stretched wire. The whole is hung by a wire which can be twisted at the head through 180°. At the bottom is attached a paddle immersed in castor oil, which brings the instrument speedily to rest in a fresh position. The deflections are read off by a short focus telescope, placed on an arm revolving on an axis in the centre of the circle. With this instrument the dip can be determined within the fraction of a minute of a degree in less than a quarter of an hour.

With this drawing is exhibited a specimen of the thread of the Diadema Spider, also thread of the Diadema Spider cocoon.



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